

Review

Assessing ecological restoration as a research topic using bibliometric indicators



João Paulo Romanelli^{a,*}, Jaqueline Tomiê Fujimoto^b, Marcilene Dantas Ferreira^a,
Douglas Henrique Milanez^c

^a Environmental Sciences Dept. – PPGCAm, Federal University of São Carlos, São Paulo, Brazil

^b Civil Engineering Dept. – PPGEU, Federal University of São Carlos, São Paulo, Brazil

^c Materials Engineering Dept., Centre for Technological Information in Materials, Federal University of São Carlos, São Paulo, Brazil

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ABSTRACT

A bibliometric analysis was performed to evaluate the global scientific production on ecological restoration from the period of 1997 to 2017. This analysis was based on online database of Science Citation Index Expanded – Web of Science® and a total of 3297 publications was retrieved. The analysis comprised seven main aspects: (1) publication activity, (2) Web of Science categories, (3) journals, (4) countries, (5) authors, (6) organizations and (7) keywords. The results indicated that the annual publications on ecological restoration study have recently increased. The USA play an important role as they have published highly in this field and have been the most frequent partner in international collaborations. American researchers have accumulated most of the publications. The Chinese Academy of Science is the emblematic organization, with 363 published papers. The Restoration Ecology and Ecological Engineering are the two most used journals to disseminate results. The major related research areas are “Environmental Science Ecology”, “Forestry” and “Biodiversity Conservation”. Studies about “restoration”, “*pinus ponderosa*”, “climate change”, “biodiversity” and “ecosystem services” have become the main subject of research along the years. Analyses of keywords suggested that there is a relatively lack of information about “soil” and “tropical ecosystems” among the analyzed studies. Overall, this framework proved to be effective to evaluate the recent research trends and to contribute with researchers and governments on management and decision-making on science.

1. Introduction

Environmental restoration techniques have evolved significantly in recent years, especially after the emergence of the science of restoration ecology (Cole et al., 2010), which contributes to substantially enhance the body of related literature (Li and Nan, 2017). Many environmental actions, however, have not yet reached the practice aims of ecological restoration (Araújo et al., 2005; Rodrigues and Gandolfi, 2007) and this fact suggests that the real effects of biodiversity recovery and ecosystem services remain uncertain and not tested (Ren et al., 2016).

Ecological restoration appears to be one of the most promising practices to restore the integrity and functionality of ecosystems in degraded areas (Devoto et al., 2012; Balaguer et al., 2014) and it aims, among other aspects, at ensuring the sustainability of ecosystem services (Robinson et al., 2013; Hu et al., 2017) in areas affected by the negative effects of recent ecological changes (Covington et al., 2001; SER, 2002). According to initiatives such as the Convention on

Biological Diversity (CBD, 2012), the Intergovernmental Science and Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2013) and massive action policies (IUCN, 2014), ecological restoration practices are a global priority (Calmon et al., 2011; Ren et al., 2016; Aronson et al., 2016), and have been recognized as one of the United Nations Sustainability Development Goals (UN, 2015).

Therefore, to better understand part of the breadth from a particular area of science, such as ecological restoration, it is useful to conduct integrated and systematic analyses of global scientific production (Borgman and Furner, 2002; Song and Zhao, 2013), investigating the recent status and emerging trends. Some researchers have used this strategy to target their research focus (Neff and Corley, 2009; Li and Nan, 2017). In this sense, bibliometric analysis plays an increasingly important role in managing and supporting decisions in the scientific scope, technological policies and research management (Ravichandran, 2012; Song and Zhao, 2013).

Bibliometrics is a statistical technique which includes registered

* Corresponding author.

E-mail addresses: joaopromanelli@hotmail.com, joaopromanelli@gmail.com (J.P. Romanelli).

information about scientific publications, citations, patent documents and reports (Okubo, 1997; Van Raan, 2014). Recently, this technique has received special attention from the scientific community (Merigó and Yang, 2017) because it allows the integration of information on the development of specific research fields (Zhang et al., 2016) or whole disciplines (Li et al., 2011; Liao and Huang, 2014). It is a tool that benefits researchers and governments, reducing scientific boundaries between countries or regions (Yu et al., 2017).

In this field, bibliometric mapping is a striking research topic (Borner et al., 2003), since it allows the visualization of indicators presented as networks (Van Eck and Waltman, 2009). Currently, there is a lack of work applying this systematic evaluation model to assess the status and issues surrounding the theme of ecological restoration. In this study, we sought to fill this gap by developing a bibliometric analysis over the last 21 years (1997–2017), presenting a global overview and highlighting its hot spots and future trends. Specifically, this study aimed at: (1) examining trends in the “ecological restoration” research activity over the past two decades through the online subscription-based scientific citation indexing service; (2) presenting an overview about “ecological restoration” according to the distribution of papers by: publication activity, Web of Science categories, journals, countries, authors, organizations and keywords; and (3) evaluating the international collaboration networks by bibliometric mapping method.

2. Material and methods

2.1. Data collection

Bibliometric indicators have been developed considering the bibliographic data of publications indexed in the online database of Science Citation Index Expanded (SCI-E) – Clarivate Analytics' ISI – Web of Science® (<https://webofknowledge.com/>), which has an extensive and multidisciplinary coverage of bibliographic data of cutting edge scientific publications. The database is usually used as a source for academic studies (Azevedo et al., 2005; Boaneres and Azevedo, 2014) and for bibliometric studies (Okubo, 1997; Milanez et al., 2013; Van Raan, 2014). The term “ecological restoration” was designated to describe the scientific knowledge about restoration associated to ecological theories.

The search expression consisted in applying “ecological restoration” to the “Topic” field, which seeks for publications through their title, abstract, author's keywords, and WoS-assigned keywords called Keywords Plus (Boudry et al., 2018). These records necessarily brought the words “ecological restoration” in an associated way and in that exact order, due the use of quotation marks (Știrbu et al., 2015). Only articles and reviews have been considered in this analysis, because they represent the majority of documents with complete research results and outcomes (Fu et al., 2013; Boudry et al., 2018). The research comprised the timespan from 1997 to 2017 and dataset were downloaded on January 22, 2018. After searching, a total of 3297 bibliographic data of scientific publications were retrieved and collected (94.26% articles and 5.74% reviews). The assessment involved the following information obtained from the collected sample: (1) publication activity, (2) Web of Science categories, (3) journals, (4) countries, (5) authors, (6) organizations and (7) keywords. The synthesis of the methodology employed is presented in Fig. 1.

2.2. Data analyses

All analyses were performed using the “Analyzing Results” tool provided by the database with support of the MS Excel (v. 2016) to perform calculations and develop charts (indicator visualization). Maps of collaboration based on co-authorship and co-occurrence analysis were developed using VOSviewer software (version 1.6.6; www.vosviewer.com) to understand how countries, research institutions, and authors have been organizing themselves in this theme. VOSviewer

is a robust tool that uses clustering algorithms and functionalities based on the strengths of the connections among items to help the analyses of the network. The evaluation of the authors' affiliation was performed based on the “Author Information”, contained in the publications and it may not to represent all of their academic links.

To investigate the most popular research topics, their overall trends and knowledge gaps, an assessment comparing the Keywords Plus and Author's keywords has been carried out. Keywords Plus supplies additional search terms extracted from titles on cited papers and footnotes (Garfield, 1990), and include important terms for research (Boudry et al., 2018). Web of Science uses these keywords in order to improve information retrieving routines (Milanez et al., 2013). In this sense, non-repeated words or terms obtained by comparison between Keywords Plus and Author's Keywords with few occurrences were considered non-focused themes on studies about ecological restoration. The meaningless words (also called stopwords) were not taken into account, and the final listed words were separated into two groups: generic words (representing general terms) and directive words (representing specific terms). The set of directive words was used to validate the keywords analysis through a second search on Web of Science.

3. Results and discussion

3.1. Evolution of scientific activity: prior analysis

Restoration of ecosystems is an ancient practice. However, the scientific field of restoration ecology is relatively recent (Anderson, 2005). The 1980s are considered a historical landmark that characterizes the two phases of the restoration domain (Rodrigues et al., 2009; Oliveira and Engel, 2011), which is defined: by scientific knowledge associated to techniques; and by the association of these techniques with ecological theories (Young et al., 2005; Durigan and Mello, 2011).

The domain of ecological restoration has developed a broad and diversified body of literature in recent decades, which addresses several aspects of ecological interaction (Weiner, 1995; McPherson and DeStefano, 2003). This fact is relevant both to the science of restoration ecology and to the practice of ecological restoration (Young et al., 2005). The evolution of publications between the years 1997 to 2017 associated with the five main WoS Categories can be found in Fig. 2.

It is clear that ecological restoration can be considered an emerging theme of research as consequence of the general trends shown by the chart column (Fig. 2). Moreover, concerns about the environmental preservation in favor of sustainable development have been promoting the increase of the global scientific production on ecological restoration (Bloomfield et al., 2017).

In general, this topic has shown to be relevant all over the world, covering 107 different countries. Among them, the USA and China have accumulated the largest number of publications. Of course, the analysis should take into account the fact that most ISI-listed journals are published in English, which favors countries that speak this language (Okubo, 1997; Tao et al., 2015).

3.2. Main journals and most impacting papers

Overall, all retrieved papers were published in a wide range of 596 different journals. However, most journals (about 96%) have published fewer than 20 papers in the last two decades. Consequently, it is understood that these journals are peripheral in relation to scientific studies concerning ecological restoration. The top 20 most active journals, which represent about 40% of all publications, are listed in Table 1. The journal that publishes on behalf of the Society for Ecological Restoration (SER) – Restoration Ecology – is responsible for 9.7% from the total number of publications retrieved, heads the journals ranking and shows the importance of the Society.

The second most influent journal in the ranking, the Ecological Engineering, published over half of the first ranked journal (5.3%),

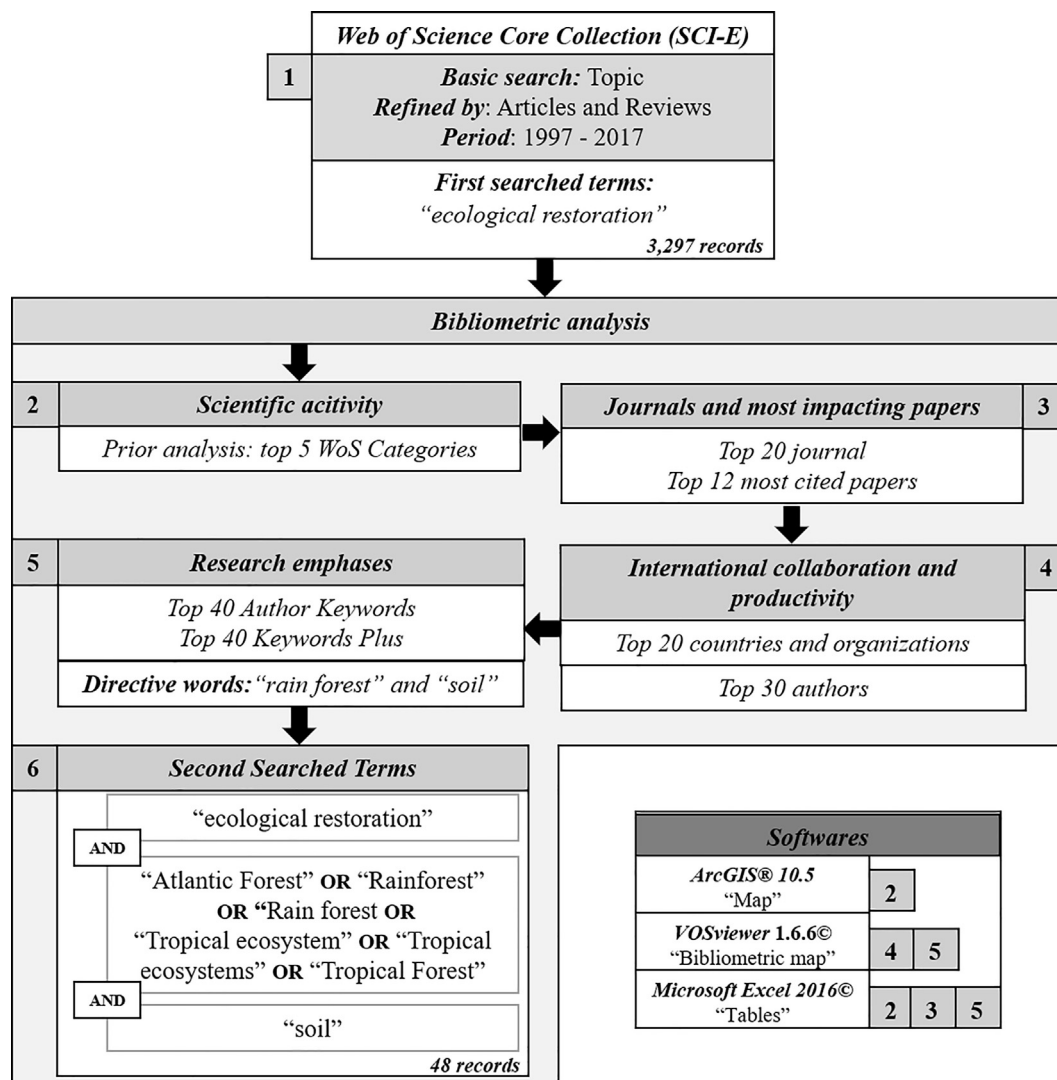


Fig. 1. Synthesis of the employed methodology.

followed by Forest Ecology and Management (4.1%), Journal of Applied Ecology (2.6%), and Ecological Applications (1.9%). This skewed distribution is expected in bibliometrics (Bradford law), since just some few journals are devoted to specific themes, although, many others may publish scientific papers about the subject (Okubo, 1997).

The analysis of the 12 most cited articles in the last 21 years (Table 2) revealed that there is no close relationship between the number of citations from a specific publication and the most active journals in the area. The most cited article on ecological restoration was published by the Journal of the North American Benthological Society, which was not listed in the top 20 journals. This study, specifically, focused on the ecological restoration of draining urban land (Walsh et al., 2005), and may have been cited not only in areas related to ecological restoration but also external to it. The most cited paper in the time span of this analysis was not vehiculated by one of the top 20 journals from Table 1. Nonetheless, some of them could be found: Forest Ecology and Management, Ecological Applications and Restoration Ecology.

An analysis of the content of the studies presented in Table 2 was performed. Two studies evaluated the management of estuarine and coastal ecosystems (ECE) (Benayas et al., 2009; Barbier et al., 2011), and establishing actions of restoration programs focused on increasing biodiversity (Benayas et al., 2009). The use of fire and the disturbance regime of forest fires on ecosystems were also frequently cited

(Schoennagel et al., 2004; Fulé et al., 1997), with a focus on the Rocky Mountain ecosystems (Schoennagel et al., 2004) and pinus ponderosa forests (Fulé et al., 1997; Agee and Skinner, 2005), from the perspective of restoring natural processes (Allen et al., 2002).

In general, the biotic and abiotic environmental changes involved with ecological restoration were discussed under the restoration and conservation aspects (Hobbs et al., 2009), and restoration ecology and population genetics (Hufford and Mazer, 2003). The effects of exotic species on the restoration process were also widely cited (D'Antonio and Meyerson, 2002). Specifically, considering the physical environment, the ecological aspects of soil restoration in mining regions were investigated (Wong, 2003). Finally, the success criteria of restoration were analyzed through guidelines of the Society for Ecological Restoration (SER) (Ruiz-Jaen and Aide, 2005) and have been received high attention from the academic community.

It must be emphasized that the longer scientific articles are indexed the higher the probability is to be cited. On the other hand, items that have been recently published and have a high number of citations may indicate new perspectives on the area (Okubo, 1997). Thus, to verify this information, an analysis of highly cited papers published in the last 5 years was also carried out, as follows.

The assisted gene flow of adaptation to local climatic changes has been frequently cited in the recent context of ecological restoration (Aitken and Whitlock, 2013), as well as restoration of forest resilience

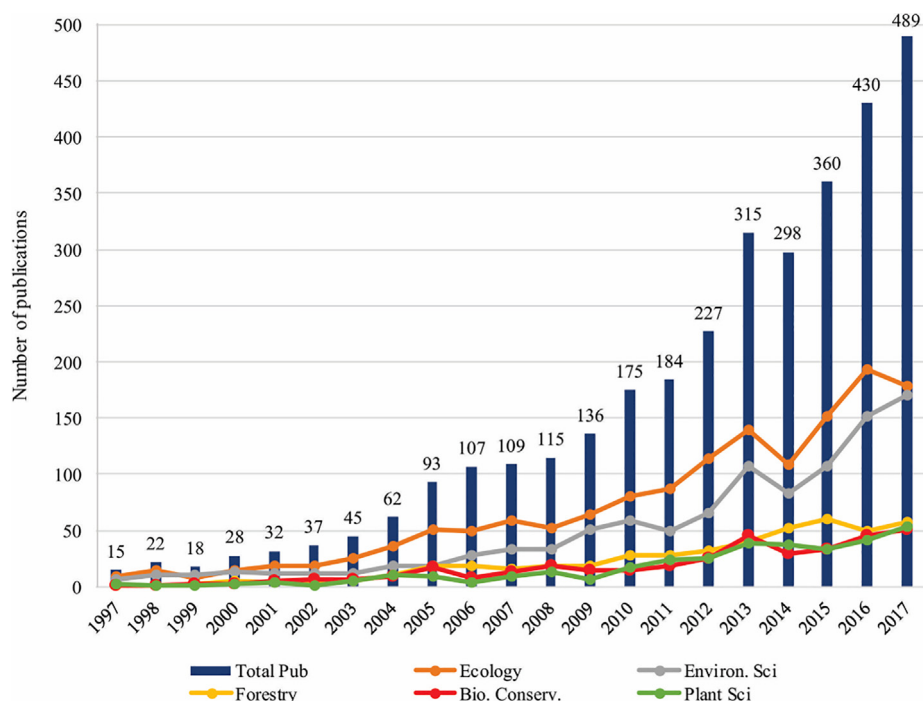


Fig. 2. Total publications from WoS Core Collection (SCI-E) involving ecological restoration from 1997 to 2017 and association to the growth trends of the top 5 main WoS categories.

Table 1

Top 20 journals ranked by total publications.

Rank	Journal	NP	Rank	Journal	NP
1	Restoration Ecology	320	11	Journal of Environ. Management	36
2	Ecological Engineering	175	12	Science of The Total Environment	34
3	Forest Ecol. and Manag.	136	13	Sustainability	34
4	Journal of A. Ecology	87	14	Conservation Biology	29
5	Ecological Applications	65	15	Environmental Earth Sciences	28
6	Biological Conservation	62	16	Biodiversity and Conservation	25
7	Environ. Management	57	17	Environmental M. and Assessment	24
8	PLOS ONE	54	18	Journal of Arid Environments	24
9	Applied Veg. Science	48	19	Ecological Indicators	23
10	Ecology and Society	39	20	Environ. Science and Pollution R.	22

Abbreviations: NP = Number of publications; 3 – Forest Ecology and Management; 4 – Journal of Applied Ecology; 7 – Environmental Management; 9 – Applied Vegetation Science; 11 – Journal of Environmental Management; 17 – Environmental Monitoring and Assessment; 20 – Environmental Science and Pollution Research.

and its spatial reference patterns (Churchill et al., 2013), and the integration of ecological restoration in global environmental policy deliberations (Aronson and Alexander, 2013). In addition, the effects of biodiversity loss, species restoration (Seddon et al., 2014), and the use of models based on functional traits have been also widely used as references. Among all subjects, the evaluation of the success criteria of restoration continues the trend of highly cited issues (Wortley et al., 2013).

3.3. International collaboration and productivity

To understand how countries, organizations and authors have organized themselves as players that conduct researches on ecological

restoration, an assessment of international collaboration based on co-authorship was carried out, considering the accumulated number of publication. Figs. 3–5 show three networks where the size of the node is proportional to the number of accumulated publications as well as the thickness of the edges. The colors indicate which cluster the item belongs to. Respectively, these figures were limited to present only the top 20 countries and organizations, and the top 30 authors.

Clearly, the USA and China have contributed significantly to the development of ecological restoration research and have published a considerable number of collaborative scientific studies (9.54% and 14.53%, respectively). The USA and Australia can be considered the core countries of this network due to the fact that they developed research in collaboration with all other top 20 countries (Fig. 3).

The bibliometric mapping of Fig. 3 also reveals the existence of two clusters among these 20 most productive countries. Specifically, cluster 1 colored in red presents the characteristic of being composed mostly by European countries, extending the collaboration network to Mexico and Brazil. On the other hand, cluster 2 (in green) consists of members from several continents and presents the largest number of accumulated publications, although it presents three members with fewer than 50 publications (Finland, India and Japan). The USA, England, France and Australia are countries which most connected members from the two clusters.

The largest number of papers with co-authorship was evidenced by the USA and China, with 119 registered documents, followed by USA and Australia (69 documents), USA and France (60 documents), USA and Brazil (50 documents) and USA and Canada (45 documents). Although some countries, such as Brazil and France, present a large number of studies in partnership with the USA, bibliometric mapping has not characterized them in the same cluster. This is explained by the strong influence of China in this scenario, which shapes the formation of clusters in function of its network of collaborations with the USA, and more specifically, with the other countries from its cluster.

Fig. 4 shows the existence of three clusters of collaboration among the most productive organizations. Cluster 1 (red) is characterized, exclusively, by North American organizations, whereas cluster 2 (green) has only members from China, highlighting the network of

Table 2
Top 12 most cited papers.

R	Year	Title	Journal	Authors	NC
1	2005	The urban stream syndrome: current knowledge and the search for a cure	<i>Journal of The North American Benthological Society</i>	Walsh, CJ et al.	920
2	2011	The value of estuarine and coastal ecosystem services	<i>Ecological Monographs</i>	Barbier, EB et al.	781
3	2005	Basic principles of forest fuel reduction treatments	<i>Forest Ecology and Management</i>	Agee, JK; Skinner, CN	545
4	2009	Novel ecosystems: implications for conservation and restoration	<i>Trends in Ecology & Evolution</i>	Hobbs, RJ et al.	533
5	2002	Ecological restoration of Southwestern ponderosa pine ecosystems: A broad perspective	<i>Ecological Applications</i>	Allen, CD et al.	468
6	2003	Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils	<i>Chemosphere</i>	Wong, MH	456
7	2003	Plant ecotypes: genetic differentiation in the age of ecological restoration	<i>Trends in Ecology & Evolution</i>	Hufford, KM; Mazer, SJ	422
8	2009	Enhancement of Biodiversity and Ecosystem Services by Ecological Restoration: A Meta-Analysis	<i>Science</i>	Benayas, JMR et al.	417
9	2004	The interaction of fire, fuels, and climate across rocky mountain forest	<i>Bioscience</i>	Schoennagel, T et al.	397
10	1997	Determining reference conditions for ecosystem management of southwestern ponderosa pine forest	<i>Ecological Applications</i>	Fulé, PZ et al.	387
11	2002	Exotic plant species as problems and solutions in ecological restoration: A synthesis	<i>Restoration Ecology</i>	D'Antonio, C; Meyerson, LA	348
12	2005	Restoration success: How is it being measured?	<i>Restoration Ecology</i>	Ruiz-Jaen, MC; Aide, TM	336

Abbreviation: R = Rank; NC = Number of citation.

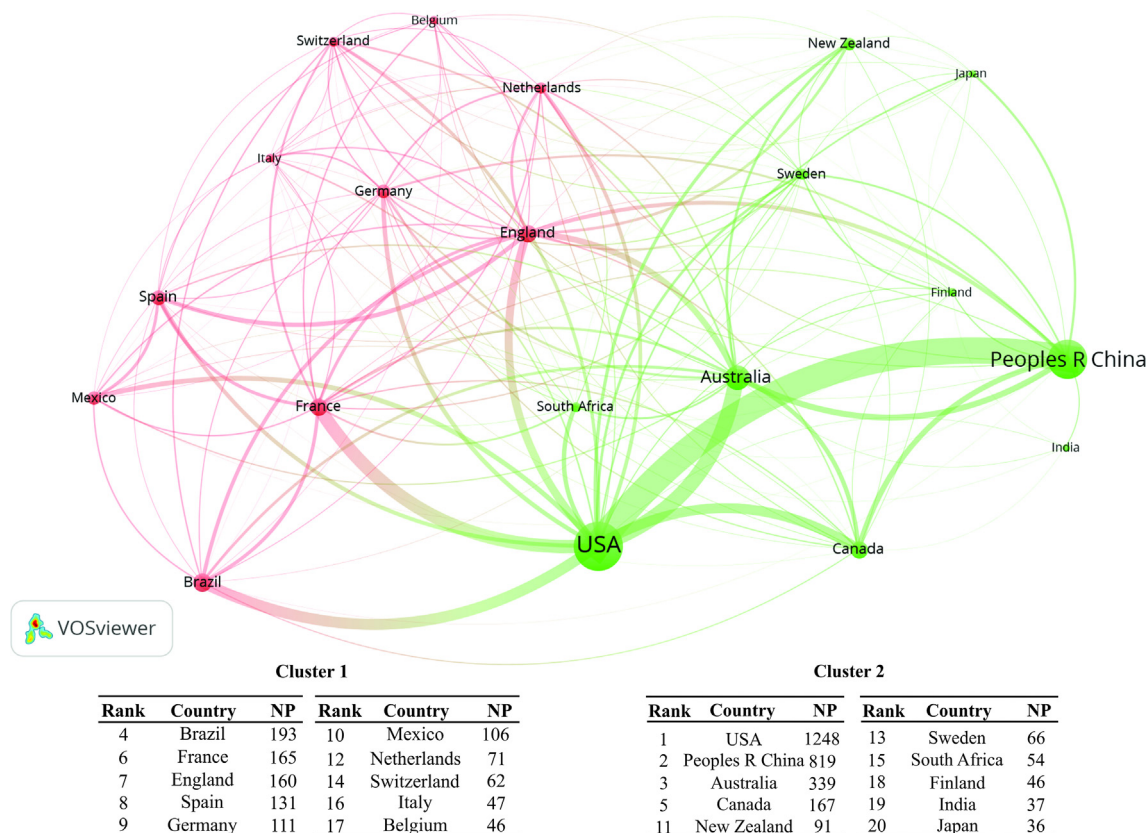


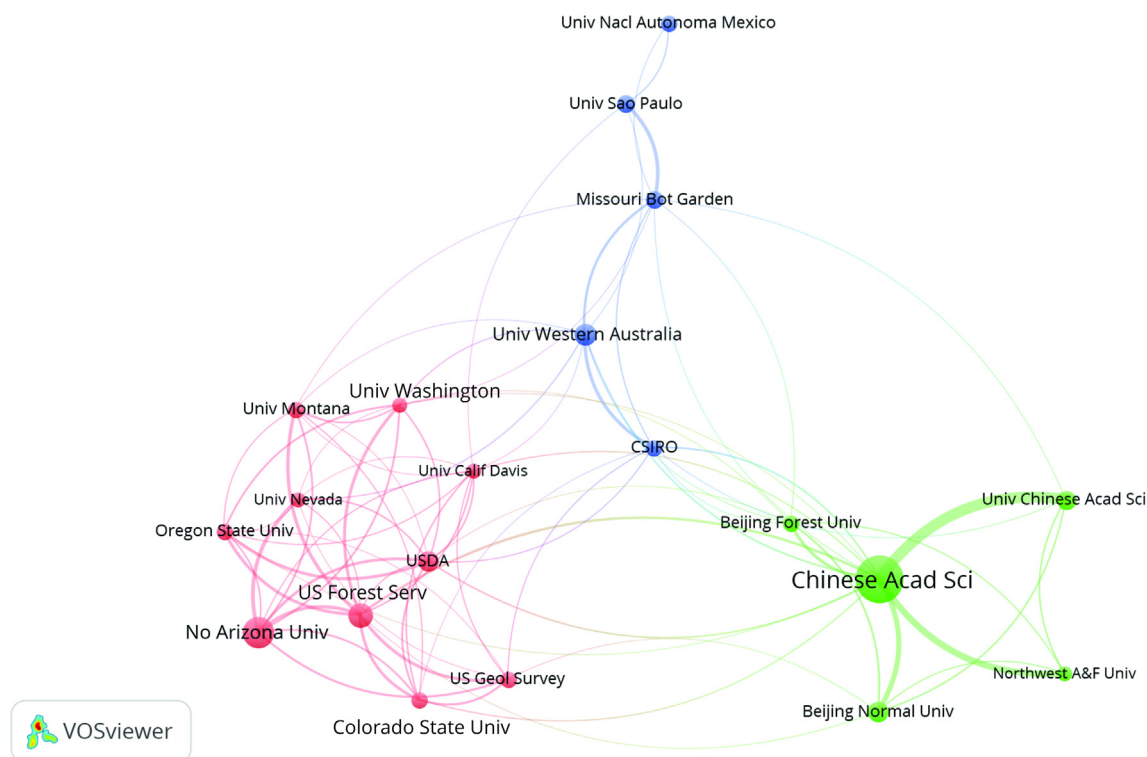
Fig. 3. Network visualization map for country collaboration. Abbreviation: NP = Number of publications = Record count.

collaboration between the Chinese Academy of Science (CAS) and the University Chinese Academy of Science (UCAS) (under the direct leadership of the CAS). Cluster 3 (blue), unlike the others, is characterized by the diversity of origin of organizations. The results show that the collaboration network between organizations from the same country (cluster 1 and cluster 2) is closer than the organizations of different countries. The organizations Chinese Academy of Science, USDA and Univ California Davis presented the largest international collaboration network: 13, 11 and 11 links, respectively. However, the organizations Chinese Academy of Science, CSIRO and Beijing Forest Univ are central organizations of this collaboration network, since they presented the largest number of collaborators among the different clusters (9, 6 and 5,

respectively).

The bibliometric mapping of the 30 main authors (Fig. 5) revealed the existence of 9 clusters of research productions. In general, it was possible to observe that cluster 1, 2 and 4 presented the most characteristic collaboration networks. The other clusters were configured as restricted collaboration networks, with few authors from the same country (clusters 3 and 5), or as single members of a cluster (cluster 6, 7, 8 and 9).

Specifically, cluster 1 has as main characteristic the predominance of American authors (9 authors), most of which are linked to Northern Arizona University (6 authors). Members Fulé PZ, Covington WW and Laughlin DC are the researchers with the largest number of partnerships



Rank	Cluster 1	NP	C	Rank	Cluster 2	NP	C
2	No Arizona Univ	159	USA	5	Chinese Acad Sci	363	CHI
3	US Forest Serv	104	USA	7	Beijing Normal Univ	75	CHI
6	US Dept Agr (USDA)	67	USA	10	Univ Chinese Acad Sci	58	CHI
11	US Geol Survey	53	USA	17	Beijing Forestry Univ	49	CHI
13	Oregon State Univ	48	USA	17	Northwest A F Univ	45	CHI
15	Univ Montana	45	USA				
16	Colorado State Univ	45	USA				
18	Univ Calif Davis	40	USA				
19	Univ Washington	38	USA				
20	Univ Nevada	37	USA				
Rank	Cluster 3	NP	C	Rank	Cluster 4	NP	C
4	Univ Western Australia	82	AUS	8	Missouri Bot Garden	56	USA
8	Missouri Bot Garden	56	USA	9	Univ Sao Paulo	53	BRA
9	Univ Western Australia	82	AUS	12	Comm Sci Ind Resr Org (CSIRO)	48	AUS
12	Comm Sci Ind Resr Org (CSIRO)	48	AUS	14	Univ N. Autonoma Mexico	46	MEX
14	Univ N. Autonoma Mexico	46	MEX				

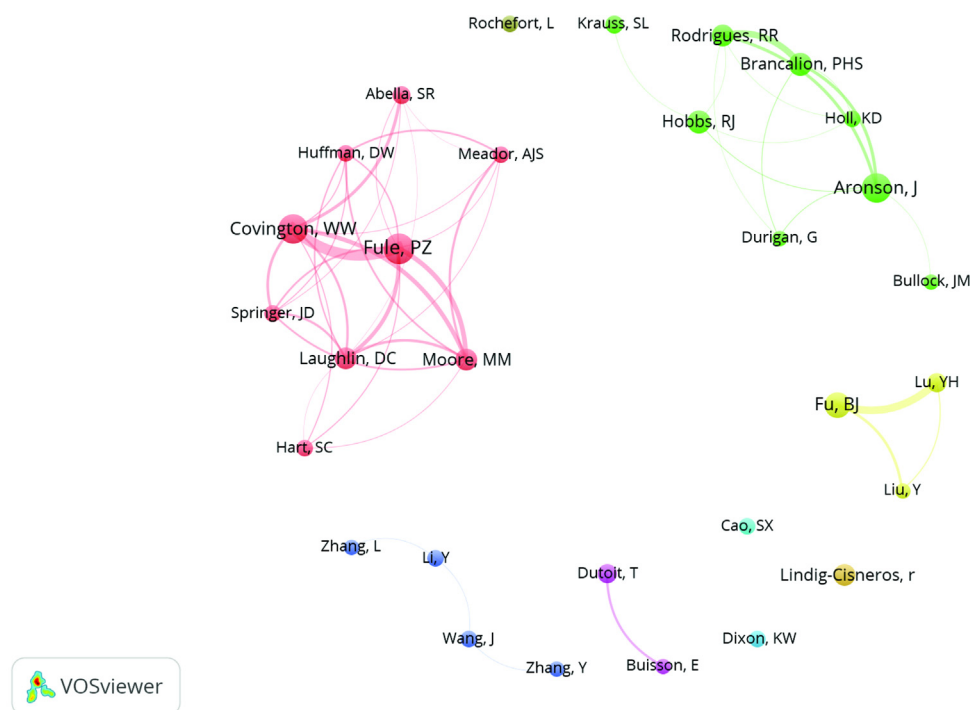
Fig. 4. Network visualization map for organization collaboration. *Abbreviation:* NP = Number of publications; C = Country; USA = United States of America; CHI = China; AUS = Australia; CAN = Canada; BRA = Brazil; MEX = Mexico; FRA = France; ENG = England; NEW Z = New Zealand.

within this cluster and also among the others from the top 30. The largest number of co-authored papers was observed among researchers Fulé PZ and Covington WW (27 documents), both linked to Northern Arizona University. In terms of origin of the authors, cluster 2 stands out for its diversity of nationalities, with members from four countries (USA, Australia, Brazil and England). In this cluster, authors Rodrigues RR and Brancalion PHS presented the highest number of papers with co-authorship (16 papers).

Although cluster 3 is composed only by members from China, the collaboration network presented a linear aspect, which indicates that there are restricted partnerships among its members. On the other hand, cluster 4, which is also composed by Chinese, presented the characteristic network aspect, suggesting that there is collaboration among all authors. This fact can be explained by the same organizational link of Chinese researchers (Chinese Acad Sci). In the same way, the members of cluster 5 also belong to the same organization (Aix

Marseille University). The other clusters (6, 7, 8 and 9) are composed by only one member, which indicates the lack of research developed in collaboration with the other top 30 authors.

Clustering techniques have been developed mainly in fields such as statistics, computer science, and network science, and play an important role in bibliometric research. These techniques are used to identify groups of related publications, authors, or journals (Van Eck and Waltman, 2017). In an international context, it was evident that there is a great diversity of research focus in the field of ecological restoration (Weiner, 1995; McPherson and DeStefano, 2003; Young et al., 2005), and this may be associated to the different research groups and the scientific demands of each region or country. In this sense, the paper contents from each author's cluster were analyzed in order to reveal the profile of subjects and study areas associated with each group. The top 50 most cited author keywords were investigated through the co-occurrence analysis (see Supplemental data for detailed



Rank	Cluster 1	NP	Organization	C	Rank	Cluster 3	NP	Organization	C
1	Fule PZ	51	No Arizona Univ	USA	18	Li Y	16	Nort China E P Univ	CHI
3	Covington WW	44	No Arizona Univ	USA	24	Wang J	14	Shenyang Agr Univ	CHI
7	Moore MM	25	No Arizona Univ	USA	28	Zhang Y	13	Zhengzhou Univ	CHI
9	Laughlin DC	25	Univ Waikato	NEW Z	30	Zhang L	13	Chinese Acad Sci	CHI
13	Abella SR	18	Univ Nevada	USA	Rank Cluster 4 NP Organization C				
16	Hart SC	16	Univ Calif Merced	USA	4	Fu BJ	36	Chinese Acad Sci	CHI
19	Huffman DW	16	No Arizona Univ	USA	12	Lu YH	19	Chinese Acad Sci	CHI
21	Meador AJS	14	No Arizona Univ	USA	29	Liu Y	13	Chinese Acad Sci	CHI
23	Springer JD	14	No Arizona Univ	USA	Rank Cluster 5 NP Organization C				
Rank Cluster 2 NP Organization C					11	Dutoit T	20	Aix Marseille Univ	FRA
2	Aronson J	46	Missouri Bot Gar	USA	25	Buisson E	13	Aix Marseille Univ	FRA
5	Hobbs RJ	28	Univ W Australia	AUS	Rank Cluster 6 NP Organization C				
6	Brancalion PHS	27	Univ Sao Paulo	BRA	20	Cao SX	14	Minzu Univ China	CHI
8	Rodrigues RR	25	Univ Sao Paulo	BRA	Rank Cluster 7 NP Organization C				
14	Krauss SL	17	Univ W Australia	AUS	15	Dixon KW	16	Curtin Univ	AUS
17	Holl KD	16	Univ Calif S. Cruz	USA	Rank Cluster 8 NP Organization C				
26	Bullock JM	13	NERC CTR E&H	ENG	10	Lindig-Cisneros R	24	Univ N A Mexico	MEX
27	Durigan G	13	State Forest Assis	BRA	Rank Cluster 9 NP Organization C				
					22	RocheFort L	14	Univ Laval	CAN

Fig. 5. Network visualization map for top 30 author collaboration. *Abbreviation:* NP = Number of publications; C = Country; USA = United States of America; CHI = China; AUS = Australia; CAN = Canada; BRA = Brazil; MEX = Mexico; FRA = France; ENG = England; NEW Z = New Zealand.

information, Figs. S1–S9).

3.4. Research emphases: keywords analysis

Keywords are an important source of information about the subjects addressed in a publication (Liu et al., 2011; Wang et al., 2013). The terms considered as keywords can be used to analyze the trends of a research area and to show the existing gaps (Guo et al., 2016). In this

study the 40 main author's keywords and keywords plus (Table 3) were considered to investigate any possible tendency. From 1997 to 2017, it was estimated that 9117 author expressions have been used in studies involving ecological restoration, which suggests the existence of a great diversity of research focus (Chuang et al., 2007). The term "ecological restoration" appears highly associated to "restoration", "*pinus ponderosa* or *ponderosa pine*" and "climate change". This first analysis suggests that among all retrieved documents involving ecological restoration, a

Table 3
Top 40 of the most frequently used keywords.

<i>R</i>	<i>Keywords Plus</i>	<i>RC</i>	<i>R</i>	<i>Author's keywords</i>	<i>RC</i>
1	Ecological restoration	886	1	Ecological restoration	891
2	Management	370	2	Restoration	282
3	Conservation	358	3	Ponderosa Pine	116
4	Biodiversity	318	4	Climate change	98
5	Vegetation	306	5	Biodiversity	97
6	Diversity	293	6	Ecosystem Services	93
7	Ecosystem or ecosystems	279	7	Forest Restoration	64
8	Restoration	262	8	Restoration ecology	63
9	Forest or Forests	221	9	Conservation	61
10	Climate change	209	10	Invasive species	53
11	Ecosystem services	174	11	Succession	52
12	Communities	154	12	Revegetation	47
13	Growth	149	13	Prescribe Fire	45
14	Impacts	148	14	Genetic Diversity	43
15	Plant or plants	143	15	Adaptative Management	40
16	Soil	140	16	Disturbance	37
17	Dynamics	131	17	Species richness	37
18	Patterns	124	18	Forest Management	35
19	Land-use	119	19	Grassland	34
21	Ecology	105	20	Fire	33
20	Succession	105	21	Monitoring	32
22	Species richness	96	22	Reforestation	32
23	Landscape	95	23	Resilience	32
24	Establishment	94	24	Vegetation	32
25	Regeneration	92	25	Thinning	31
26	Nitrogen	82	26	Diversity	30
27	Plant communities	81	27	Eutrophication	29
29	Disturbance	79	28	Ecosystem function	28
28	Grassland	79	29	Rehabilitation	28
30	Water	79	30	Remote sensing	28
31	Fire	78	31	Carbon sequestration	27
32	Rain forest	76	32	Loess Plateau	26
33	Habitat	72	33	Nitrogen	26
34	Responses	72	34	Ecosystem Management	25
36	Land	65	35	Local adaptation	25
35	Perspective	65	36	Community Assembly	24
37	Ponderosa Pine Forests	63	37	Sustainability	24
38	Populations	62	38	Wetland	24
39	Systems	59	39	Competition	23
40	Model	57	40	Functional traits	23

Gray color = repeated words or synonymous. Abbreviations: R = Rank; RC = Record count.

considerable amount of studies have addressed temperate forest ecosystems, which can be evidenced by the main plant species that was cited as author-keyword.

Many scientists are committed to the study of ecological restoration. However, many questions remain unclear (Ren et al., 2016). To detect the gaps surrounding the theme, the strategy of comparison between keywords plus and author's keywords were used (Table 3), in order to verify what is being discussed in the papers, although, it was not a specific research subject (author's keywords). Comparing these two groups of words, it was noticed that in some cases words are repeated

and others are not. Moreover, some terms, although they are not written in the same way, can be considered as synonyms (eg. community assembly and communities, or genetic diversity and biodiversity).

Furthermore, after separating words with the same meaning, non-repeated words and stopwords, the following list from keywords plus it was obtained: dynamics, establishment, growth, habitat, impacts, land, landscape, land-use, model, patterns, perspective, populations, rain forest, regeneration, responses, soil and water. Among this group of words, were considered as generic words: dynamics, establishment, growth, habitat, impacts, land, landscape, model, patterns, perspective,

populations, land-use, regeneration and responses; and as directive words: rain forest, water and soil.

In addition, it is possible to consider that there are some knowledge gaps in the context of ecological restoration involving the directive words. They were highly cited as keywords plus (words extracted by WoS from cited papers – titles and abstracts), consequently, they are important terms in this domain. However, they were rarely used or not frequently included as author's keywords, what suggests they were not the main focus of study. Thus studies involving the set of directive words may be an incipient research area.

Taking everything into account, to validate these results, a second search on Web of Science was conducted (Fig. 1) combining the main term “ecological restoration” along with the two directive words considered as the most important ones: “rain forest” (and its main synonyms) and “soil”. After the search, 48 documents were retrieved from the initial amount (3297 documents) from the first search, which represents about 1.5% of all publications. Therefore, it was possible to confirm that there is a lack of knowledge involving this specific set of subjects into the domain of ecological restoration. It is important to highlight that this second search involves not only keywords, but also the title and abstract.

4. Conclusions

In conclusion, this work evaluated the researches on ecological restoration from 1997 to 2017 through bibliometric analysis to understand quantitatively the tendencies of the body of literature related to the theme. The bibliometric mapping proved to be effective in evaluating the networks of connections between the selected items, making it easier the interpretation of the obtained results. The main evaluated aspects revealed the rapid development of the domain of ecological restoration, mainly after 2006, where more than 100 studies were registered per year.

The networks of collaborations tend to present new configurations according to the scope of the research (number of analyzed items) and the employed terms at the initial search. In general, rankings tend to be influenced by: i) the coverage of papers and citations in the database; ii) how the indicators are calculated; and iii) the assessed disciplines. Indicator rankings display the visibility of the scholar results in some specific database, not their impact on the whole academic community (Wildgaard, 2015).

Application of boolean operators and quotation marks was the key factor to retrieve the selected data of this research. The analysis of cooperation among countries, organizations and authors have shown that the international collaboration network is less expressive than the collaboration between the organizations or authors from the same country, which tends to direct the studies to some specific research areas, as it was evident in the analysis of the author's cluster.

Based on the analysis of the keywords and author's cluster, it is suggested that future studies should contemplate the following aspects: (1) the systemic approach to ecological restoration, seeking to circumvent the gap of information about soil; (2) ecological restoration of tropical ecosystems and other critical ecosystems; (3) ecological restoration addressing anthropogenic and environmental issues in an integrated manner. In addition, other critical points of study are likely to emerge with the advance of ecological restoration studies. Finally, this work revealed the current status of research and knowledge gaps on ecological restoration, which may favor the development of new studies and the global scientific production.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.ecoleng.2018.06.015>.

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